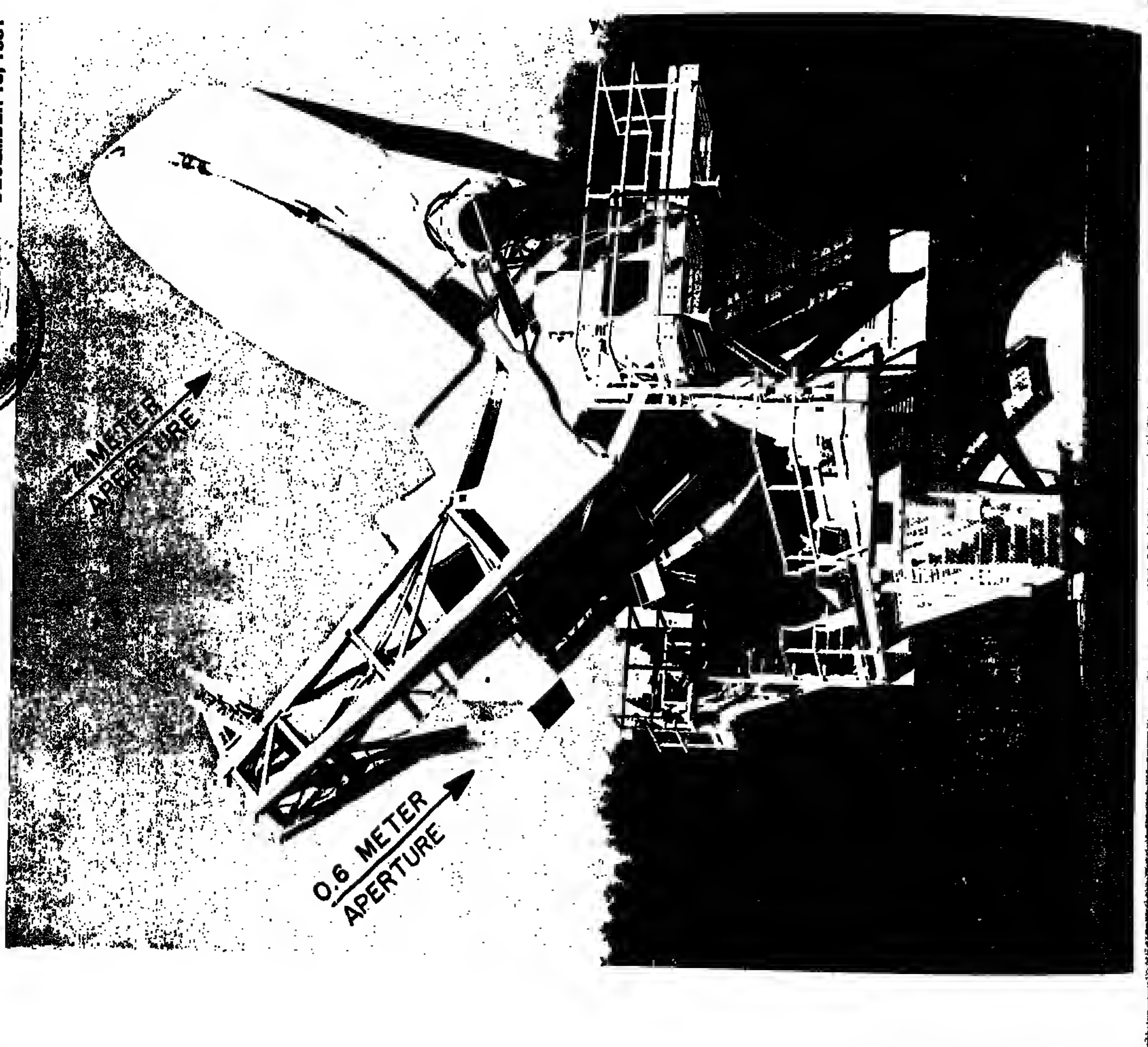
EOS TRANSACTIONS, AMERICAN GEOPHYSICAL UNION VOLUME 62, NUMBER 50, DECEMBER 15, 1981



EOS, TRANSACTIONS, AMERICAN GEOPHYSICAL UNION VOL. 62, NO. 50, PAGES 1177-1192 DECEMBER 15, 1981

Tectonophysics

Volcanology

General or Miscellaneous

The Challenge of Climate to Man

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How vulnerable is the United States and world food supply to a serious drought today? Will the burning of fossil fuel and the subsequent release of CO_2 to the atmosphere alter global climate? Is society today sufficiently resilient to respond to major climatic changes? Is there a coming ice age?

The Climate Challenge

Around 900 A.D. a group of small villages was established in northwest Iowa by Indians of what we now call the Mill Creek culture. Around 1400 A.D., after many prosperous years, the villages were abandoned. In the summer of 1963, archeological and geological excavations of several sites of the Mill Creek culture began. While three major sites were excavated, one known as Phipps site provided the clearest historical record of civilization in the area. To reconstruct both the habits of the Mill Creek people and the environment in which they lived, scientists have studied a wide assortment of remains preserved in the strata of northwestern Iowa. Unnoticed without the aid of a microscope are the remains of pollen grains blown into the area from surrounding trees. The pollen preserved in the strata can be read as an historic log of changes in the vegetation and climate surrounding the Mill Creek area. The village was occupied about 900 A.D. on the flood plain of Mill Creek. The pollen evidence shows that during the 10th and 11th centuries, the Indians lived in a region with tall-grass prairie on the uplands and woods on the valley terraces and valley floors. This vegetation is not very different from today's if one substitutes 'cornfield' for 'prairie.' From evidence given by fossil bones found in the strata, it seems that deer and elk were abundant and were hunted by these Indians. The Indian meat diet appears to have been dominated by these animals, supplemented only occasionally by bison. Maize was the main agricultural product.

Toward the end of the 12th century major environmental changes occurred at Mill Creek. The influx of oak pollen began to decline rapidly, while populus (probably cottonwood) rose rapidly. The proportion of bison meat eaten by the Indians rose abruptly at this time. Within a few decades in the 12th century the vegetation in the entire area changed from tall-grass prairie on the uplands and forest in the larger valleys to steppelike vegetation and essentially only phreatophytes along the streams in all but the major valleys. From radiocarbon-dated samples of charcoal and from the accumulation rate of sediment at the site, the rate of pollen changes in this area can be estimated. The decline of oak pollen from its maximum to minimum occurred in less than a century. The rapid rise of grass pollen took about 45 years; the rise of phreatophytes about 15 years.

The interpretation of the changes in pollen preserved in the Mill Creek sites and the changes in feeding habits of the Mill Creek Indians suggest the beginnings of a long-term drought. In perhaps one or two generations (45 years) the tall-grass prairies were replaced by short grass. The few cottonwoods and willows along the stream banks were the only remains of the forest that once filled the valleys. The deer, a woodlands browser, disappeared, and two thirds of the meat eaten by the Mill Creek people came from bison, a short-grazing animal. Further west of the Mill Creek sites, other archaeological evidence indicates that the farming villages disappeared entirely.

The Mill Creek site has been extensively studied by Reid Bryson and his colleagues at the Institute for Environmental Studies of the University of Wisconsin [*Bryson and Baerreis*, 1968; *Bryson et al.*, 1970]. Their documentation of the drought conditions in this area during the 12th to the 14th century is relevant to society today since this area is now a major spring wheat, maize, and soybean region for the United States. The drought at Mill Creek forced the abandonment of a corn-farming community which had lasted for 500 years.

Today, centuries later, in a highly developed technological society, we still face problems similar to those of the Mill Creek Indians, although we possess much greater powers of hindsight and foresight in the matter of climate variability and change. There is growing apprehension, for example, that man-made increases in atmospheric CO_2 are contributing to a global climate warming on a scale yet to be experienced in historical times. There is some scientific evidence to suggest that such a change could spell a gradual warming and drying of the environment once occupied by the Mill Creek Indians and now the center of U.S. agricultural production. In the more immediate future, there is renewed concern over the possibility of a recurrence of a severe drought, an event which threatens sudden disruption to an increasingly global food system.

Problems of both long-term climate change and short-term variability—of CO_2 and drought in particular—are explored at greater length in this essay.

Eos

TRANSACTIONS, AMERICAN GEOPHYSICAL UNION

The Weekly Newspaper of Geophysics

Send double-spaced manuscripts (four copies) to *Eos*, AGU, 2000 Florida Avenue, N.W., Washington, D.C. 20009, or send them directly to one of the associate editors with a copy to the above address.

Eos, Transactions, American Geophysical Union (ISSN 0096-3941) is published weekly by the American Geophysical Union from 2000 Florida Avenue, N.W., Washington, D. C. 20009. Subscription available on request. This issue $5.00. Second-class postage paid at Washington, D. C., and at additional mailing offices.

Cover. Schematic illustration of the components of the climatic system. Dark arrows are examples of external processes; open arrows are examples of internal processes in climatic changes. (From a U.S. Climate Program Plan, NOAA, Department of Commerce.)

Drought in the Great Plains

Man and drought have been at odds since the dawn of civilization. In the continental U.S., droughts have been known, according to historical documents, since the early 1800's [*Ludlum*, 1971].

To a first approximation, droughts have occurred in the midwestern U.S., and the Great Plains in particular, roughly every 20 years, although their distribution and intensity have been quite different for each drought period. For example, the droughts in 1910, 1911, 1913, and 1917 were short, severe, and spatially limited, as was the drought in the 1960's. The drought of the 1930's, however, was widespread and persistent. No drought since has equaled the intensity, areal extent, and persistence of the drought of the 1930's.

The severity and duration of aridity in the area can be related to moisture balance by a meteorological index developed by *Palmer* [1965]. The Palmer Drought Severity Index (PDSI) is based on an empirical water balance approach. The normal amount of precipitation received in an area is dependent on the average climate and the meteorological conditions of the area both during and preceding the month or period in question. The Palmer index computes the required precipitation for any area. The difference between the actual and computed precipitation is a measure of the deviation of the amount of moisture from the long-term mean. The index is structured to correspond to a wide range of moisture conditions, as shown in Table 1.

TABLE 1. Drought Severity Index (PDSI)

Palmer Index		Degree of Drought
	≤ −4.0	Extremely dry
−4.0 <	≤ −3.0	Severely dry
−3.0 <	≤ −2.0	Moderately dry
−2.0 <	≤ −1.0	Mildly dry
−1.0 <	< +1.0	Near Normal
+1.0 ≤	< +2.0	Mildly wet
+2.0 ≤	< +3.0	Moderately wet
+3.0 ≤	< +4.0	Severely wet
+4.0 ≤		Extremely dry

Classification of moisture conditions, based on a scheme developed by the meteorologist, W. C. Palmer. Index refers to meteorological rather than soil conditions.

The PDSI is one of several drought indices calculated by Department of Commerce/NOAA for the entire U.S. The index can be read as a measure of local areal moisture that is relative to the long-term mean. The formula for making the calculation also includes a 'memory' term for conditions during previous months. An important property of the PDSI is that the same number in different locations means roughly the same relative degree of drought.

Figure 1, for example, shows the reconstructed PDSI values for 64 climatic divisions in the Great Plains for the period 1931 to 1977 [*Warrick*, 1980]. These data show that the drought of the 1930's has not been duplicated, in both intensity and duration, by subsequent droughts. The 1950's drought matched that of the 1930's in severity but was limited to certain portions of the central and southern Plains. Isolated drought occurred in the 1960's and 1970's.

The fact that there is a well-known (but poorly understood) sunspot cycle of nearly 22 years and drought occurrence in the Great Plains of nearly every 20 years is often the basis for postulating links between these activities. *Mitchell et al.* [1979] have provided some empirical evidence for coincidence in frequency between sunspot activity and drought intensity. These authors built their analysis on the established relationship between variation in the width of trees and climate [*Fritts*, 1976]. In their study the variations in tree ring width for the western U.S. was correlated with calculated values for PDSI. An equation relating the two variables was derived and used to determine PDSI for times before meteorological records. In the end, PDSI were determined for approximately 40 localities west of the Mississippi River for the period from 1700 to the present. Areas where the PDSI were of equal values (−4, −3, −2, and −1) then were grouped for each year to produce a Drought Areas Index (DAI). This index was then analyzed by spectral techniques. The dominant frequency identified in these series was 22 years. Thus both sunspot activity and drought frequencies in the western U.S. have the same frequency. Mitchell et al.'s detailed analysis and conclusion provide an excellent perspective on what this coincidence means.

> From the viewpoint of solar physics and solar terrestrial mechanisms of potential relevance to climate, our results would clearly seem to imply a role of solar magnetic activity in giving rise to widespread drought in the western U.S. This role may be either direct or indirect. It is our impression that the solar control of drought is not to be construed as a prime mover of drought or of climatic aberrations that result in drought. Rather, we prefer to think that the solar control is in the nature of a modulating mechanism, that alternatively favors or discourages the spread of drought at times when terrestrial climatic development[s] unrelated to solar events are primed to erupt into a drought situation.

These results provide no justification for using solar variability as a reliable basis for climate or drought prediction. 'Our data make it abundantly clear that a wet year can arrive at a time when the Sun "says" it should be a drought year, and that a major drought can develop when the sun "says" there should be no drought.'

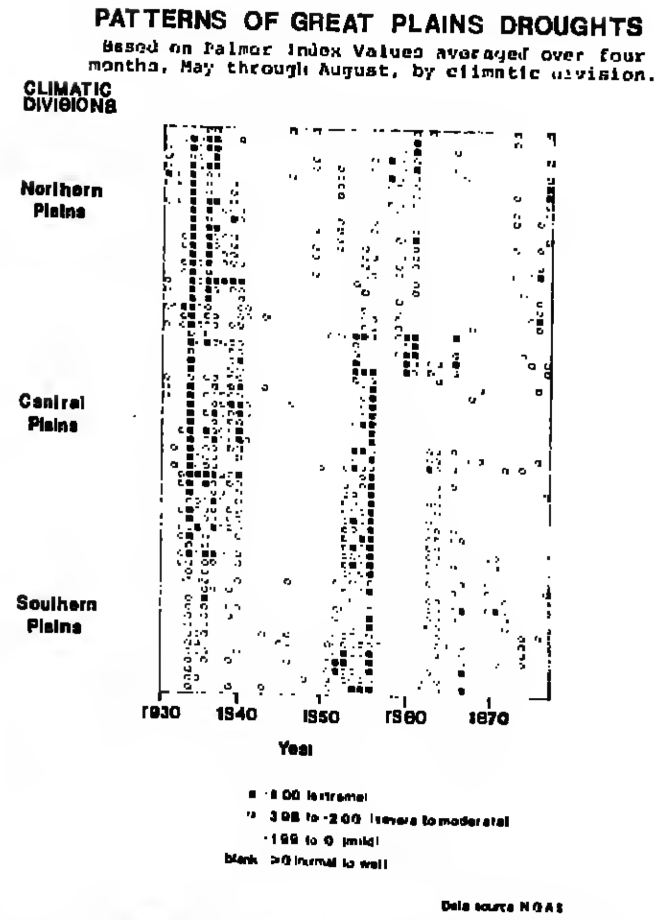

Fig. 1. Patterns of Great Plains droughts by geographic division, based on PDSI values averaged from May through August (From *Warrick* [1980]; reproduced with permission of the author.)

Drought and International Politics

The lessons of Mill Creek and the historic records of drought in the Midwest underscore the recurrent nature of drought and its impact on society. From the time of the first sodbusters in this region, in the late 1800's, to today, the Great Plains has grown in importance as a major food-producing area. It accounts for 12%–15% of the world's total wheat production and 61%–65% of the nation's wheat. The U.S. also provides 40%–45% of the world's total wheat trade.* This blessing from the land is the product of sophisticated technology and a generally favorable climate over the last 100 years.

The question of how much each of these variables (technology and weather/climate) affect crop yield is controversial and unresolved. It is an extremely important question, however, since it affects the types of management strategies used in agricultural decisions. One school of thought maintains that the sensitivities of crop yields to drought has

*Figures are based on 1975–1978 in Agricultural Statistics, 1979 USDA.

†The National Climate Program Act: Hearings before the Subcommittee on the Environment and the Atmosphere of the Committee on Science and Technology (94th Congress, 2nd Session).

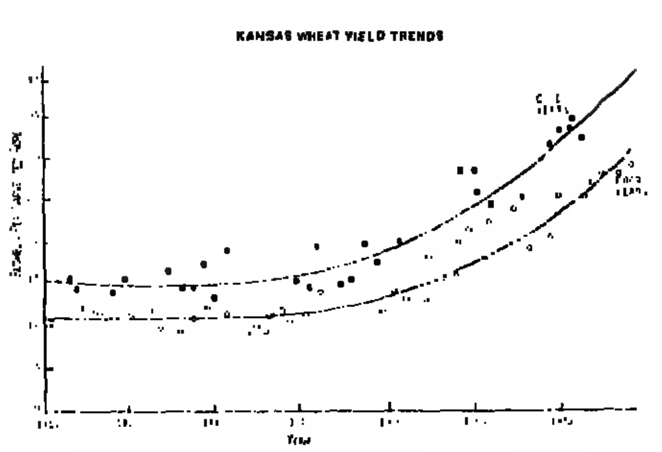

Fig. 2. Trend in wheat yield in Kansas. (From *Warrick* [1980]; reproduced with permission of the author.)

been reduced (over the past 30 years) because of advances in technology [see, for example, *Newman*, 1978]. A second school of thought suggests that crop yields are sensitive to sharp declines from drought, even given new technological advances [as, for example, *McQuigg et al.*, 1973].

A major barrier for resolving this question is the stubborn problem of separating weather and technological factors in agricultural production. It is probably unrealistic to expect a solution to the problem when comparisons are made at the level of large geographic areas that cross climatic and/or geologic zones. *Warrick* [1980] suggests a different approach to the problem that focuses on states, crop-reporting districts (which coincide with state climatic divisions for the Great Plains), or counties. His analysis of wheat yield in Kansas over the period 1890 to the present suggests a sensitivity to drought conditions. Figure 2, for example, shows yield trends in Kansas separated by good weather and bad weather years. If technological improvements in yield type or in management have occurred over this period, it might be expected that the two curves for good and bad weather years would in time converge. In other words, if the agricultural system had become better in dealing with drought conditions, the relative difference between expected good yield and expected poor yields would decrease over time, but they do not. In terms of absolute bushels the curves in Figure 2 actually diverge. This is a warning, at least for wheat production in Kansas, that agriculture has not completely engineered climate out of the picture of crop production.

As the Midwest is an important food source, a danger lies ahead in not knowing how resistant the area is to a recurrence of a 1930's-type drought. Richard Warrick at the National Center for Atmospheric Research and his collaborators at Clark University are addressing one of the more important questions of the time, namely what would be the global impact if such a drought occurred in the Great Plains. Warrick's important preliminary findings from linking climate yield and global food trade models suggest that a recurrence of a 1930's drought in today's world might induce famines in grain-import-dependent regions that would exceed, in total deaths worldwide, any similar catastrophe since the 1930's. Further model-linking analyses are being performed to explore this question in greater detail [*Warrick and Kates*, 1981].

The relationship between climate and society today is far more complex than during Mill Creek times. Complex management decisions and political, economic, and social patterns today can serve to increase or lessen the environmental impact of climate change. The 1968–1973 drought in semiarid West Africa (Sahel) is a case in point.

Social scientists have documented that political, economic, and agricultural factors were partly responsible for the magnitude of the crisis in the Sahel [*Glantz*, 1977]. Man may have helped create or intensify the drought by destruction of vegetation which, in turn, increased surface albedo and thereby decreased rainfall [*Charney*, 1975]. This process can turn marginal lands, such as the Sahel, into deserts.

The lesson of Mill Creek, in a broad sense, is to underline the relationship between climate and man. Climate can be thought of as a natural resource, a concept originally developed by *Landsberg* [1946]. How society responds to climatic fluctuation, how it manages its resources in light of climatic change, and how it may alter global climate by its own activities may well be measured, by the year 2000, in economic terms, population increase, and perhaps world famine. National and international programs are now being developed to understand better the role of climatic processes in shaping the world's economy and welfare.

Policy Implications

The decade of the 1970's was characterized by sufficiently adverse social and weather conditions in many parts of the world as to suggest to many in policy, management, and government positions that more attention should be paid to understanding the impacts of climate on society. A 1974 report from a committee of the existing Domestic Council ('A United States Climate Program') said:

> The food and energy crisis is being sharply intensified throughout the world by the natural fluctuation of regional climate. Longer-term changes in climate, whether naturally occurring or resulting from man's activities or both, may be leading to new global climate regimes with widespread effects on food production, energy consumption, and water resources. These circumstances have created an urgent need for a program that can offer hope of knowing and anticipating the effects of climate fluctuations and changes here (U.S.) and around the world. A U.S. Climate Program is proposed which will enable the U.S. Government to meet this need.

Between 1974 and 1977, while numerous government committees and the National Academy of Sciences developed various aspects of an integrated U.S. climate program, the U.S. Congress began considering legislation for the initiation of a national climate program. On May 18, 1978, the House Subcommittee on the Environment and the Atmosphere (of the Committee on Science and Technology) met under the chairmanship of Congressman George Brown (D., Calif.) for the first of 8 days of hearings on the subject of climate and related research.*

Congressman Brown's opening remarks reiterated the theme that the 1970's were turbulent social and climatic times.

> I am sure that events in recent years have made us all aware of the impacts of climate on mankind. Perhaps the most memorable event was the drought in Russia in 1972, which led to the infamous grain sale. Along with the concurrent failure of the Peruvian anchovy fishing due to a changing ocean current, this was one of the major causes of the spectacular inflation in food prices during 1972 and 1973. More recently, we have seen the effects of a disastrous drought in the Sahel, failures in the Indian Monsoons, and closer to home, a drought in the northern part of California which is badly affecting this year's crops.

Despite the above perception, there is actually no evidence that climate everywhere is becoming more variable. *Chico and Sellers* [1979], for example, have examined the variability of mean monthly temperatures in the United States since 1898. Their results show that the interannual variability was greatest in the decade centered on 1930, and it has decreased steadily to a minimum in the decade centered around 1970. This trend in variability is almost completely explained by changes in variability during the winter months of December to February. The great change in variability for the U.S. occurred in the Midwest. Even if variability has not changed significantly over the past decades, the effects of climate variability have been felt on society through economic and social hardship.

For example, the economic impact of the abnormally cold winter of 1976–1977 in the eastern half of the United States in agricultural losses alone was approximately $2 billion. [Source: *State Government News*, April 1977, published by Council of State Governments.]

Estimated Crop and Capital Investment Losses During Winter 1976–1977

Arkansas—$39 million total losses, including soybeans and hay. Future pasture production could require lengthy recovery.
Georgia—Cattle producers hurt, pastures diminished.
Indiana—$5.87 million loss to livestock, which will be difficult to recover, and another $10.5 million agricultural loss, including milk dumped.
Kentucky—$108 million total losses, much of it to livestock and to increased feed and labor cost for livestock.
Louisiana—$60 million in cattle and crop losses, with long-range figure much higher. Many cattlemen sold foundation stock. Much of sugar cane and citrus crop lost.
Massachusetts—Problems with transportation of products and feed.
Maryland—Agricultural losses of $25 million, including livestock, broilers, wheat, and tobacco. Seafood industry lost 40–50 days of harvest time in Chesapeake Bay that will have a long-range effect on oyster and blue crab industry.
Michigan—$158,000 in milk dumped because of snow-blocked roads.
Mississippi—Excess of $100 million in losses, chiefly in cattle industry. Following months of unprofitable cattle operations, the winter caused a severe strain on the ability of cattlemen to recover. Stress on breeding herds will be felt a long time.
New York—At least $3.5 million in agricultural damage, some $0.5 million worth of milk dumped, and $750,000 dairy cattle lost because of barn collapses.
Ohio—Total loss of $15.2 million, including 93,000 livestock.
Pennsylvania—Milk dumped; peach, winter wheat, barley, and alfalfa crops affected; pigs sold at loss; increased feed costs and barn cave-ins.
South Carolina—Total loss of $41.2 million in feed and cattle. Livestock producers need 93,363 tons of hay and 1.3 million bushels of grain to maintain herds. Request for federal aid denied.
Tennessee—Up to $10 million in losses.
Virginia—Total reduction in value of farm production of $150–$160 million, including 1.2 acres of hay and pasture affected and crop, nursery, livestock, and capital investment losses. Potential farm income reduced by 11%.

Total monetary losses $2,356.6 million.

The 1980 summer drought in the Midwest and south central United States has also had significant economic and health effects. While the full impact of this drought is not yet known, the heat and lack of moisture has reduced crop yield significantly below previous year yields, and total estimated crop losses are over $1 billion [*State Government News*, Aug. 1980].

While the 94th Congress considered the need for a national climate program, no legislation was successfully developed. One year later, in June 1978, additional hearings were held by the Committee on Commerce, Science and Transportation of the U.S. Senate.

The 95th Congress eventually passed a Natural Climate Program Act (P.L. 95-367), which was signed by President Carter on September 17, 1978. The act is designed to establish a comprehensive and coordinated national climate program. The act is a realization that the effects of climate have important social, economic, and political consequences and this should be given consideration in policy and resource planning. A 5-year plan to implement specific goals of this national plan has recently been prepared by the National Climate Program Office.

While, since 1974, the U.S. has promoted the concept of a national climate program, similar developments have been underway in Europe. In February 1979, the World Meteorological Organization (WMO) convened the first 'World Climate Conference,' as a beginning in the development of a World Climate Program (WCP). The WCP, which became effective in January 1980, will now be the focus for large-scale international programs in climate research and service.

Additionally, the United Nations, through its Environmental program (UNEP) is taking a lead role in promoting programs to study the impact of climate on society. One major issue on UNEP's agenda is the impact of CO_2 on climate and the resulting impacts on society.

The Climate System: Recognizing Signal From Noise

The effect of CO_2 or any other anthropogenic influence on climate must be distinguished above the natural background of climate variability. Climate varies on all time scales, only a sampling of which is discussed below.

The earth's climate is characterized by its constant state of flux. It is the product of the interactions of the atmosphere, oceans and cryosphere, and the earth's surface. The cover figure shows a simple representation of these processes operating within what may be called the 'climate system,' and processes operating on the climate system. Radiation from the sun provides the fundamental energy that drives this system. The variation of chemical and aerosol constituents of the atmosphere, such as CO_2 and dust, act to change the amount of radiation incident on the earth's surface. The radiation, once received at the earth's surface, drives the atmospheric circulation, which in turn is closely linked to the circulation of the oceans. Together the interaction of the atmosphere and oceans are influenced by the extent and thickness of the ice covering the land and sea.

Although weather and climate are sometimes used interchangeably, there are important distinctions between them. Weather is the state of the atmosphere (described as completely as possible with present observing capabilities) at one point in time. Weather prediction attempts to forecast a new condition of the atmosphere—given an initial atmospheric state—by the application of fundamental laws of atmospheric motion.

Climate results from an ensemble of weather events for a season, year, or longer period. A climate state is usually defined in terms of average conditions as well as some measure of the variability within the time period under consideration.

Although the same physical laws apply to both weather and climate, climate prediction is complicated by the need to consider complex interactions (as well as changes within) all components of the earth's climate system. For example, while it may not be necessary to consider the small changes in ocean temperature or circulation from one day to another for a successful weather forecast, such changes become important when predicting atmospheric changes from one season to another. Similarly the changes in the geometry of the earth's orbit occur on a time scale that is important for deducing climate changes over thousands of years, but they are of no consequence to weather forecasting.

Climate Variability: The Last 100 Years

A summary of the major features of climate variability on several different time scales is shown in Figure 3. Northern Hemisphere average temperatures for the past 100 years show a general trend of increasing temperatures from the 1880's to the 1940's, and declining temperatures thereafter. These temperature change are on the order of tenths of a degree, although the change from 1880 to 1940 is a change of nearly one full degree centigrade.

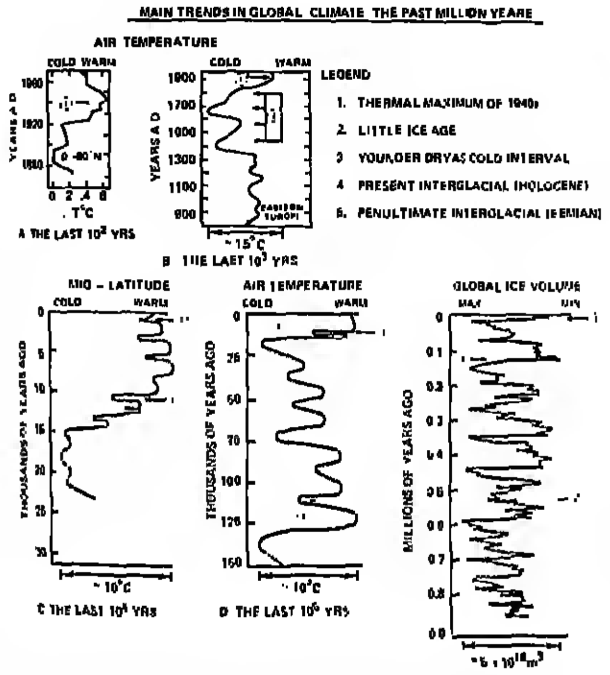

Fig. 3. Main trends in global climate over the past 1 million years. (From Report of the Ad Hoc Panel on Present Interglacial, Federal Council for Science and Technology, 1974.)

Although one of the most widely quoted climatic curves, it is one of the most perplexing to explain. This temperature record is characterized by large annual changes which tend to obscure trends in the curve. Temperatures have declined since 1940 but have leveled off since 1965. Since then, surface temperatures have shown only a slight warming of 0.1° to 0.2°C. For average temperatures between surface and an elevation of 15,240 m, there has been no detectable change in temperature since 1965. Whether or not the fluctuations in this curve are natural or, in part, affected by anthropogenic factors is unknown. The curve has all of the principal characteristics of a temperature series produced by stochastic processes [*Robock*, 1979]. The trend in temperature over this 100-year period is also inversely correlated with the transmissivity of the atmosphere [*Bryson and Goodman*, 1979]. There exist many other climate time series for all or part of the last 100 years, including data on sea surface temperatures and atmospheric pressures. *Barry et al.* [1979] provide a short review of these climate indicators and what they say about short-term climate variability. Most of the data sets are relatively short (30 years or less) and cannot be used to document longer-term variability in this time period.

Climate Variability: The Last 1000 years

Figure 3b provides a general picture of climate variability over the past 1000 years. For this time interval there is no direct measure of climate comparable to the Northern Hemisphere temperature curve shown in Figure 3a. Rather there are localized climate records compiled from observational, historical, and proxy data. *Lamb* [1969], for example, has compiled an index of winter severity in Europe from historic documents. *LaMarche* [1974], using variations in tree ring widths as a proxy indicator of temperature and moisture, has reconstructed a near 1000-year climate record for mountain areas in California. *Dansgaard et al.* [1971] have developed a unique climate record for Greenland, based on isotopic chemical changes in ice cores, and *Fritts et al.* [1979] have reconstructed, from tree ring variations, a 400-year temperature, precipitation, and air pressure record for the United States. These and many other climate records indicate that the early part of the last millennium, from about 900 to 1200 A.D., was generally warm and is referred to as the Medieval Warm Period. By contrast, the period between 1430 to 1850 was significantly cooler in Europe and eastern North America and is referred to as the Little Ice Age.

Some finer detail of climate variability over part of this time interval for the U.S. can be seen in the tree ring data analyzed by Fritts. Fritts' data allow a comparison of the general characteristics of each season for the past 400 years as reconstructed from tree ring variations. Some simple statistics can show how often severe winters like 1976–1977 and 1977–1978 have occurred in the past. During the 378 years from 1602 to 1978, the frequency of winters with a circulation pattern like 1976–1977 was 0.178 or 17.8 years per century. The frequency of winters like 1977–1978 was 8.6 years per century. Frequencies of winters like 1976–1977 varied the most from one century to another and were very frequent in certain time intervals. For example, the reconstructed circulation patterns between 1615 to 1685 resemble the winter of 1976–1977 with a frequency of 57.4 years per century. During the same time interval, the winters of 1977–1978 occurred only 12.5% of the time. From 1887 to 1729, no reconstructed winter circulation pattern resembled the winter of 1976–1977, and only 8% were similar to 1877–1978.

While there are many suggested causes for climate variability on this scale, a relationship with solar activity, as measured by sunspot occurrence, is often given prominence. While solar activity as measured by sunspot numbers has varied in a quasi-periodic fashion since the 1700's, there appears to have been a minimum of solar activity during the late 17th century. *Eddy* [1976], working from historic documents of visual sitings of sunspot activity, identified the period 1650–1710 as a low in sunspot activity. While *Landsberg* [1946] has recently identified, from newly studied historic diaries in Germany, a large number of sunspot and auroral observations made during the period 1685–1688, the total number of observed sunspots was still much less in the mid-17th century than at later periods. This period of time, termed the Maunder minimum, corresponds in time with a part of the 'Little Ice Age' in Europe. This correlation has been widely cited as a reliable link of sun and climate. It may not be so.

Historical data, by its very nature, is often incomplete and imprecise. Using such data as the sole basis for establishing a minimum of sunspot activity is therefore bound to be controversial. Reliable physical evidence that is accurately measured and global in representation does provide better proof of varying solar behavior. This evidence comes from carbon-14 fluctuations as observed and recorded in the annual growth of trees.

The production rate of carbon-14 in the upper atmosphere changes with time because the galactic cosmic ray flux responsible for C^{14} production is modulated by changes in the magnetic properties of the solar wind. Changes in the atmospheric C^{14} level are recorded in the annual growth of trees. Thus the C^{14} levels derived from tree rings can be tied to the sun's modulation of the cosmic ray flux in the vicinity of the earth, and this provides a history of solar changes. *Stuiver and Quay* [1980] have determined the C^{14} changes in trees over the past 1000 years. This C^{14} record, used in conjunction with a carbon reservoir model that describes the terrestrial carbon exchange between the atmosphere, ocean, and biosphere, allows determination of a curve of changes in C^{14} production rate (Figure 4*a*).

Because the C^{14} production rates are dependent on neutron flux rates, which in turn are related to solar activity, the C^{14} production rates should be compatible with and inversely related to sunspot activity. Stuiver and Quay have shown that the production rate index does correlate with observed sunspot behavior (Figure 4b, dashed line). From the C^{14} production rates and the carbon reservoir model, Stuiver and Quay have been able to develop a theoretical long-term record of sunspot behavior. This proxy record (Figure 4*b*, solid line), which is fine tuned to the observed record, is characterized by two periods other than the Maunder minimum, when sunspot activity was low. The Sporer minimum occurs between 1418 and 1534, and the Wolf minimum between 1282 and 1342.

This important proxy record of sunspot behavior permits a direct test of possible links between solar minimums and climate. For example, do the times of the Sporer and Wolf minimums coincide with periods of cooler climates? The results of such comparison [*Stuiver*, 1980] indicate that there is no clear relationship, on this time scale, between sunspot behavior and climate. The earlier Wolf minimum appears to be coincident with a part of the Medieval warm period. It is thus becoming increasingly more difficult to link, in any straightforward fashion, sunspot and climate changes.

Climate Variability of the Last 10,000 and 1 Million Years

On these long time scales (Figure 3(*c–e*)), climate has been characterized by alternation between glacial and interglacial conditions. Over the past million years, ice ages have occurred many times, and only (on this time scale that is) 18,000 years ago a large part of the Northern Hemisphere lay under thousands of feet of ice. The last 10,000 years has been characterized by processes leading to a deglaciation and subsequent evolution of modern climate. Because of the very important and exciting work by *Hays et al.* [1977], we now know that a major factor in the timing of past ice ages over the last million years has been due to changes in solar radiation received by the earth as a result of changes in the geometry of the earth's orbit. These orbital changes move and tilt the earth away from and toward the sun with a frequency of 19,000, 23,000, 41,000, and 100,000 years. Considering that 18,000 years has elapsed since the last ice age, a model of future climates, based on orbital theory and ignoring anthropogenic effect, predicts that the long-term trend over the next several thousand

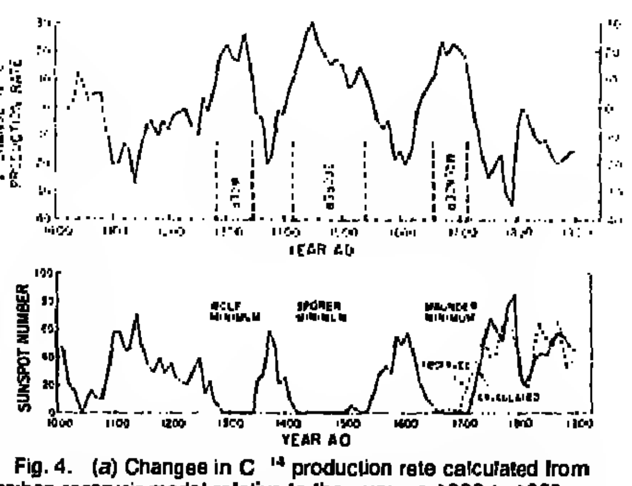

Fig. 4. (*a*) Changes in C^{14} production rate calculated from carbon reservoir model relative to the average 1000 to 1860 production level; (*b*) Sunspot numbers as observed (dashed line) and calculated from production rate. (After *Stuiver and Quay* [1980] and reproduced with permission of the authors.)

years is toward glacial conditions. It is against this long-term trend that anthropogenic factors must also be measured.

While there are exciting things to say about climate variability on these long time scales, it is beyond the scope of this discussion, which emphasizes shorter-term climate variability. Long-term climate change is nicely discussed in *Hecht* [1979], *Barry et al.* [1980], and *Mitchell* [1970], who also provides an elegant discussion of climate variability in general.

CO_2 Effect on Climate

Long-term future changes in the earth's climate may be related to the burning of fossil fuels. This comes about because the burning of these fuels releases large amounts of carbon dioxide (CO_2) into the atmosphere. CO_2 is a gas which absorbs infrared radiation emitted by the earth's surface, and thus as its concentration in the atmosphere increases, so does the amount of heat it traps on the earth's surface. This 'greenhouse' effect may result in a global warming of a magnitude exceeding anything seen on the earth for millions of years.

It is not a recent hypothesis that man is affecting his environment by increasing the concentration of CO_2 in the atmosphere. As early as 1938, G. Callendar recognized that man, through the burning of fossil fuels, could change the composition of the atmosphere and affect climate. Nearly 20 years later, *Revelle and Seuss* (1957) put the CO_2 question into global perspective. They said.

> Human beings are now carrying out a large scale geophysical experiment of a kind which could not have happened in the past nor be repeated in the future. Within a few centuries we are returning to the air and oceans the concentrated organic carbon stored over hundreds of millions of years.

It is now nearly 23 years later, and in 1980 the documentation for the rise of CO_2 in the earth's atmosphere is at hand. The proof comes from direct measurements of CO_2 in the atmosphere at Mauna Loa, Hawaii, and other monitoring stations.

In 1957, as part of a research program developed for the

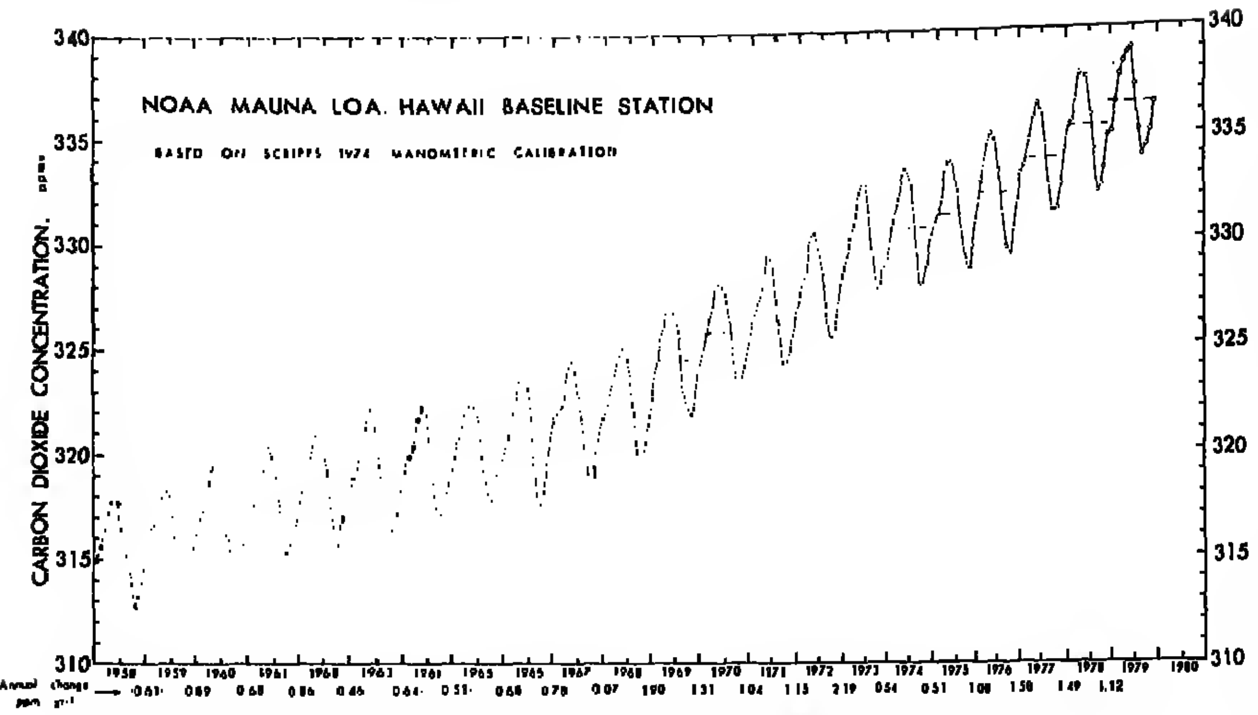

Fig. 5. CO_2 level recorded at Mauna Loa, Hawaii (in ppm) and annual changes. (Reproduced courtesy of NOAA.)

International Geophysical Year, laboratories were established at Mauna Loa (elevation 3400 m) and the South Pole to begin accurate and regular measurements of CO_2 in the atmosphere. The monitoring at Mauna Loa has resulted in the observations shown in Figure 5. The curve clearly shows seasonal variations in respiration-photosynthesis, with an amplitude of about 6 ppm. Maximum CO_2 occurs in April, minimum in October. The decrease represents the excess photosynthesis uptake of CO_2 over decay and respiration during the Northern Hemisphere summer. In addition to the seasonal signal from these data it is clear that since 1958 the amount of CO_2 in the atmosphere has steadily increased. The current value of 336 ppm, or 700×10^{15} g C, represents an increase of 20 ppm since measurements began in 1958. Estimates of the amount of CO_2 in the atmosphere prior to 1958 are between 265 and 290 ppm (550 to 620×10^{15} g C). Thus between 80 and 150×10^{15} g C have been contributed to the atmosphere since preindustrial days. CO_2 produced by industrial activity from 1860 to 1979 is about 160×10^{15} g C (Table 2). Approximately 80×10^{15} g C of this amount was contributed between 1958 and 1979. The source for these data on CO_2 emissions from the burning of fossil fuels are UN records, which may be subject to an error of 10% or 15%; the data are, however, continuous and internally consistent. From 1860 to 1970 the CO_2 emissions from fossil fuels grew at a rate of 4.3% per year, except for the periods of world wars. If CO_2 production continued at this rate, annual CO_2 production would approximately reach 14×10^{15} g C by the year 2000 and 41.5×10^{15} g C by 2025.

The increase in CO_2 production has declined over the past 10 years and is now about 3.6%. The amount of CO_2 emissions from fossil fuels can be projected reasonably for the next 20 years, since the time required to make major shifts in energy production or consumption is of this magnitude. Predictions beyond the year 2000 are much more difficult to make and are a product of complex interactions of demographic, economic, and social variables.

The measurements at Mauna Loa of CO_2 (Table 2) in the atmosphere over the period 1960–1979 show an increase of 9.5 ppm from about 317.2 to 335 ppm. This increase is 6% and is equivalent to an additional 39×10^{15} g C.

Since the beginning of the CO_2 measurements at Mauna Loa, the observed increase has accounted for about 50% of the carbon dioxide released by the burning of fossil fuel and destruction of vegetation. The other 50% has been added to the other carbon reservoirs, which are the oceans and the biosphere. Estimates of CO_2 remaining in the atmosphere vary between 48% and 56% [*Broecker, et al.* 1980]. While at first there was considerable discussion that the biosphere itself, through deforestation, was also a major contributor of CO_2, it now appears that this contribution is small and that to a first approximation the fossil CO_2 released to the atmosphere can be adequately accounted for in existing carbon cycle models [*Broecker et al.*, 1980]. (This point is controversial, however, and I am treating it casually in this review, since the topic is mainly climate change. Further discussion is given in reviews of the global carbon cycle, as for example *Bolin et al.* [1979].)

CO_2 Effect on Climate

The primary effect of an increase of CO_2 in the atmosphere is to cause more atmospheric absorption of thermal radiation from the earth's surface and thus to increase air temperature. Numerical modeling of this process with global atmospheric general circulation models (GCM) suggest a global warming of the earth of about 2°C with a doubling of CO_2 and 4°C with a quadrupling. The model experiments indicate that the warming is greatest in polar regions, where the increase may be 3 times as large as in tropical regions. Climate simulations with increased levels of CO_2 also provide estimates of changes in the pattern of evaporation and precipitation and in the extent of sea ice. The value of these experiments is primarily as diagnostic tests of climate models and their intercomparison. Although present climate models do capture the main large-scale features of the atmosphere, they are severely limited in portraying oceanic-atmospheric interactions, cloudiness, and detailed regional climate changes. Large-scale ocean modeling comparable to existing atmospheric modeling is not presently available because of both lack of observational data on appropriate synoptic scales and inadequate understanding of major oceanic mixing and circulation processes. Thus present GCM's of both atmosphere and ocean are capable only in a modest way of duplicating the observed climate. Simulations of climate with increased levels of CO_2 must be viewed in the context of the capabilities of these models to simulate modern climate. (A review of the strengths and weaknesses of climate modeling is beyond the scope of this report, but I recommend the referenced papers given by *Barry et al.* [1979] in their review of climate change.) Herein, I can discuss only the most recent results of large-scale climate modeling with increased CO_2 levels and compare the results to previously published reports.

Manabe and Stouffer [1980] simulate global climate with 2 and 4 times the present level of CO_2, using the sophisticated general atmospheric circulation and simplistic ocean model developed at the Geophysical Fluid Dynamics Laboratory (GFDL). The model consists of an atmospheric GCM and a mixed-layer ocean model with uniform thickness. Like most GCM's this model predicts changes in vertical components of vorticity, divergence, temperature, moisture, and surface pressure from the basic equations of motion, thermodynamics, and continuity.

The ocean model is a static isothermal water layer of uniform 68 m thickness. This thickness assures that the heat storage associated with the annual cycle of sea surface temperature is included in the model.

The model is run beginning with isothermal, dry, and motionless atmosphere and with an atmospheric concentration of CO_2 at 300 ppm. Stable climate conditions develop after about 10 years of model time. The control experiments successfully reproduce the observed basic features in the seasonal variation of the atmosphere. In response to a quadrupling of the CO_2 level of the atmosphere, the model produces a new equilibrium climate which shows an overall global average increase of 4.1°C in surface temperatures. Low-latitude changes are on the order of 3°–4°C; high-latitude changes are 6°–8°C in the Southern Hemisphere and 6°–14°C in the Northern Hemisphere. Figure 6 shows the latitude height distribution of the difference in zonal mean air temperatures between an atmosphere with the present and 4 times the amount of CO_2. Estimated temperature changes are half as great for a doubling of CO_2 levels.

Manabe and Stouffer [1980] give an excellent discussion of the results of their experiment with regard to the latitudinal and seasonal variation of the changes in precipitation, evaporation, and sea-ice distribution. In general the model shows greater moisture content of the air and an increase in the poleward transport of moisture. Additional moisture generated in the tropics is transported to high latitudes, and both precipitation and runoff rate increase. As temperatures increase in the Northern Hemisphere, sea ice is reduced. With 4 times the CO_2 level in the atmosphere, sea ice disappears completely from the Arctic Ocean during a few summer months.

The global model used in this study contains many simplifications and idealizations. Some important physical processes, such as the horizontal heat transport of ocean-by-ocean currents are not considered. In attempting to simulate the present climate, the surface air temperature over the entire circum-Antarctic Ocean is overestimated, resulting in the underestimation of the area covered by sea ice.

The results of this model suggest a somewhat lower global temperature increase than previously estimated by these and other authors. The differences are not great, and there is a general convergence of a ±2°C temperature increase for a doubling of CO_2. This number is generally higher than estimates derived from simple radiation balance models, which for the most part record only the expected atmosphere response to CO_2 increase in the atmosphere independent of atmospheric and oceanic feedback processes. For example, *Newell and Dopplick* [1979] assume that the CO_2-induced change of temperatures and mixing ratio of water of surface air is zero when they evaluate the CO_2-induced changes in sensitive and latent heat flux from the earth's surface to the atmosphere. Thus the warming of surface temperature is greatly underestimated.

Most of these models suggest a greater warming in the polar regions than in the tropical ones. Since the West Antarctic ice sheet is thought to be relatively unstable in comparison to the remainder of the ice cover over Antarctica, there is concern that this ice sheet might disintegrate or surge because of the temperature increase. There is, however, considerable disagreement among glaciologists about the likelihood of a collapse of the West Antarctic ice sheet. A recent meeting of experts (Orono, Maine 1980), sponsored by the Department of Energy, produced recommendations for a research program to clarify conflicting opinions.

It is not clear at this time how to verify that any global increase in temperature (should it occur over the next decades) is due to CO_2. Because the intermediate layers of the ocean are expected to absorb some of the increased heat, any atmospheric increase in temperatures may be delayed behind the CO_2 input by perhaps several decades [*National Academy of Sciences*, 1979]. Thus it is not obvious how a global warming, such as that which occurred between 1850 and 1940, presumably due to non-CO_2 effects, may be distinguished from a predicted warming due to CO_2.

If average global temperatures were indeed to increase, new patterns of evaporation and precipitation would likely develop. The effect of such a change would be felt everywhere. The Manabe-Stouffer experiment discussed above suggest that some regions would become wetter, others drier, most warmer, and some colder. The ultimate consequence would be a global society and a global ecosystem which would be forced to adapt to a new climatic state with a different distribution of temperatures and precipitation, winds, humidity, and the like. How climate variability would change as a result of changes in CO_2 level is unknown. It is, however, variability of climate, more than slow climate change, which affects the economic and social well being of society.

Living with Climate Change

As a theme for this article, I have centered on drought as an example of a climatic extreme that has significant impact on society. While a drought of the magnitude of the 1930's has not occurred since, other climatic variations from drought to extreme cold have been characteristic of the past decade. As discussed above, the perception that climate is becoming more variable has given rise to international and national programs designed to understand better the causes of climatic change and to utilize better existing knowledge of climate variability in decision making and resource management.

The impact of climate on society is both a product of the climate change itself and the vulnerability of society. Whether society today is more or less vulnerable to major climatic changes (than in the past) is a research question for the decades ahead. Even given no climate change, can society manage its affairs with increased population, energy, and food demands. The report of the Council on Environmental Quality, Global 2000, suggests a grim future picture for world society as the result of overpopulation, limited fuel resources, and severe water shortages. Water availability may, in fact, be the single most important environmental variable in the decades ahead.

For the past 30–40 years, the normal water supply in most U.S. river basins has been adequate for agricultural, industrial, and municipal purposes. As population increases and industry develops (particularly in the Southwest), the balance between available water and water needs becomes critical. For part of the Colorado River Basin, the water shortage is already quite evident.

TABLE 2. Annual and Cumulative Industrial CO_2 Production and Measurement of CO_2 in the Atmosphere, Recorded at Mauna Loa

Year	Cumulative Industrial CO_2, 10^{15} g C	Cumulative CO_2, ppm	Increase Over Previous Year in Table, %	CO_2 at Mauna Loa, ppm
1860	0.09	0.042		
1880	3.27	1.53		
1900	6.19	2.90		
1920	26.01	12.22		
1940	47.20	22.17		
1960	83.27	39.12		[illegible]
1970	117.08	55.00		[illegible]
1971	121.47	57.06	0.037	[illegible]
1972	126.03	59.06	0.035	[illegible]
1973	130.66	61.47	0.040	[illegible]
1974	135.74	63.77	0.037	[illegible]
1975	140.59	66.05	0.035	[illegible]
1976	145.84	68.42	0.037	[illegible]
1977	150.62	70.85	0.035	[illegible]
1978	156.03	73.30	0.034	[illegible]
1979	161.50	75.87	0.035	[illegible]

Data through 1976 from *Bolin et al.* [1979]. Data from 1977 through 1979 courtesy of William Elliott (NOAA).

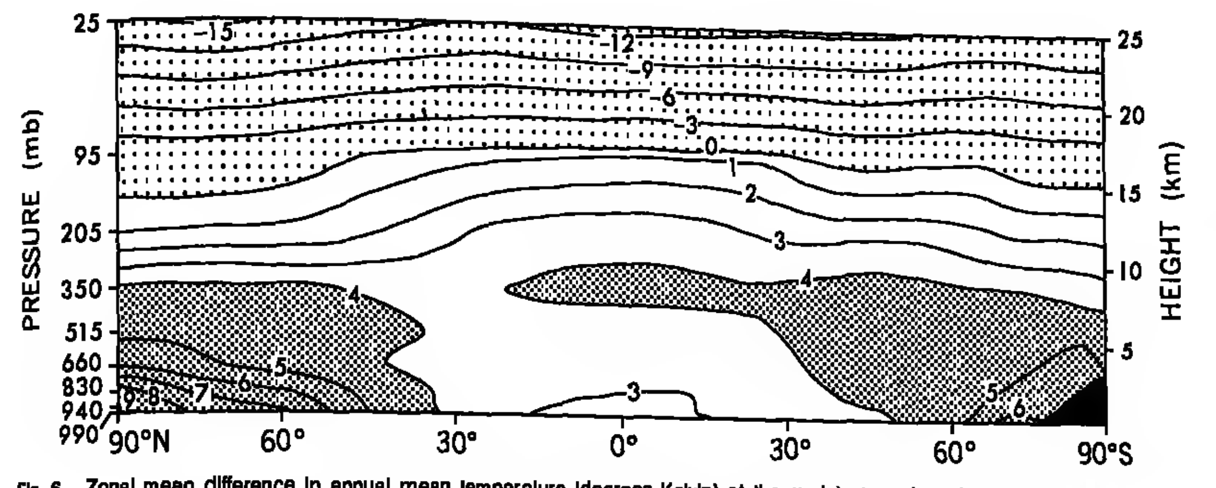

Fig. 6. Zonal mean difference in annual mean temperature (degrees Kelvin) of the model atmosphere between 4 times CO_2 and present levels. (From Manabe and Stouffer and reproduced with permission of the authors.)

Suppose there is a climate change of some degree between now and the year 2000, what would be the effect on the 18 major water regions of the U.S.? *Stockton and Boggess* [1979] have made a preliminary comparison of present supply and demand for water, with projected values for a scenario of ±2° warmer or colder and ±10% greater or less precipitation. In general, most regions east of the Rocky Mountains would not be drastically influenced by the hypothetical climatic changes above. Local problems of flooding, transportation, or waste management could be met by alternate management strategies.

River basins west of the Mississippi River, however, could experience significant shortages under a warmer and drier scenario. Stockton has calculated, using his hydrologic model, that the increased water evaporation from water surfaces, soil, and plants caused by a rise of 2°C in mean annual temperature accompanied by a 10% decrease in total precipitation could result in decreases of 40% to 60% in annual surface water supplies. Climate changes of this magnitude have occurred naturally over the past 150 years. The regions that would suffer major impacts would be Arkansas, White-Red, Texas-Gulf, Rio Grande, Upper and Lower Colorado, California, and Missouri. As groundwater reserves are already heavily utilized in these seven regions, it cannot be considered a viable alternative supply to supplement surface water shortages.

For the climatic scenario of cooler (by 2°) and wetter (by 10%), the national impact would be mostly beneficial. Regions that would be mildly adversely affected because of excess water would include the South Atlantic Gulf, New England, Lower Mississippi, and Great basins.

Thus the danger lies ahead for the western U.S., where under drier conditions, severe water shortages can be expected. Even in the absence of any climatic changes, water shortages may be likely because of the increased need for water in the development of energy sources, for agriculture, and for the increased industrialization and expansion of municipal areas. While planning for water excesses has been done for many years (flood control, zoning, land management, etc.), planning for water shortages is not well advanced. Considering that most groundwater sources in the western U.S. are being used up faster than they are replenished, the problem of water management in the western U.S. may be one of the most serious problems of the year 2000.

In fact, it may be the problem of water availability that determines how society may respond to CO_2 climate change. A report of the National Academy of Sciences on how CO_2 induced climate changes might affect society concluded that

> . . . changes in availability of water are the single most significant consequence of climate change through the next century—while modest precipitation increases in areas well supplied at present could be accommodated, similar decreases in some currently marginal semiarid regions and increases in the frequency of drought could have serious impacts.

Food and water are intimately related, and I conclude this long essay by again returning to drought and agriculture in the Midwest. The feat of growing corn in a semiarid region like western Kansas is made possible by heavy irrigation of the groundwater from the Pliocene age Ogallala formation, which underlies parts of the high plains. In most of the high-plain region, groundwater withdrawals are far in excess of recharge. To meet the demands of agriculture and population in this area in the year 2000 will require extensive water management systems, such as the existing groundwater management districts (GWMD), which permit users to determine the level of water consumption. Additional options for supplementary groundwater demands may involve the transfer of water from the Missouri River or other water basins. Such projects would involve gargantuan costs—even by today's monetary standard; or in the extreme case, with diminishing water resources, western Kansas, like areas of Texas, could revert to sagebrush. More likely, as reported by John Walsh ('What To Do When the Well Runs Dry,' *Science*, *210*, 754–756, 1980), western Kansas could change from irrigated corn agriculture to the raising of less water-intensive crops and, perhaps ultimately, to dryland farming of wheat and grain sorghum.

The problems for U.S. farmers today, like farmers during the 1930's and like Indians of Mill Creek, is living and working in the world with a climate that is unpredictable from year to year. Unlike the Indians of Mill Creek we have extensive technology available to us to insulate society from extreme weather or climate events. Unlike the Indians of Mill Creek, abandonment of the land is not our only option. But like the Indians of Mill Creek we remain strongly affected by climate. It is one natural resource that is still a challenge to men.

Acknowledgments

I am grateful to several colleagues who reviewed drafts of this article and who corrected many of my silly mistakes. They are Lester Machta and William Elliott (NOAA), who also provided Figure 6; Reid Bryson (U. Wisconsin); John Perry (National Academy of Sciences); Richard Warrick (NCAR), who also gave permission to reproduce Figures 1 and 2; Ken Bergman (NSF); and J. Murray Mitchell (NOAA). Figure 7 was also provided by S. Manabo (GFDL); Figure 5 by Minze Stuiver (U. Washington). Uncorrected mistakes are my own, and opinions expressed in this article are mine and do not represent the official position of the National Science Foundation.

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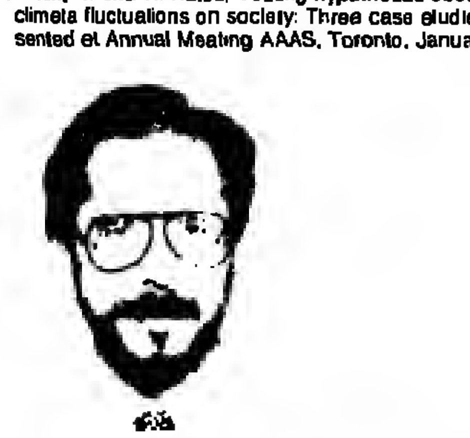

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News

COSOD Update

The Conference on Scientific Ocean Drilling (COSOD) (*Eos*, December 1, p. 1162) 'identified a set of global scientific objectives ranging from the continental margins to the deep sea that will require a worldwide program of drilling in the Atlantic, Pacific, Indian, and polar oceans,' explained Roger L. Larson, chairman of the COSOD Steering Committee.

However, COSOD did not aim to provide scientific goals for the Ocean Margin Drilling Program (OMDP). The main

The 12 top-priority scientific programs, with relevant questions, identified at COSOD are listed below in nonpreferential order. This list still is subject to revision by the COSOD Steering Committee and will almost certainly evolve as the future ocean drilling program proceeds.

Processes of magma generation and crustal construction at mid-ocean ridges. What is the composition of the oceanic layer? Is the ophiolite analogy a valid model for ocean crust?
The configuration, chemistry, and dynamics of hydrothermal systems. What are the dimensions and characteristics of open versus closed and active versus passive hydrothermal systems?
Early rifting history of passive continental margins.
What is the shallow and deep structure of stretched and listric-faulted margins versus those characterized by excessive volcanism?
The dynamics of forearc evolution.
What are the relative motion, deformation, and pore-water characteristics of sediments being subducted at accreting and nonaccreting margins?
Forearc to back-arc structure and magmatic history.
What are the space and time relationships of back-arc spreading, compression, and volcanism at island arcs?
The response of marine sedimentation to fluctuations in sea level.
Which on-lap, off-lap sequences and intervening unconformities represent sea-level fluctuations and which represent vertical tectonic motion? What is the response of deep-sea sedimentation to sea-level fluctuations?
Sedimentation in oxygen deficient oceans.
What are the ocean circulation, paleoclimate, and potential hydrocarbon characteristics associated with Cretaceous black-shale deposits?
Global mass balancing of sediments.
What are the best estimates of the world sediment mass and composition balances in space and time?
Ocean circulation history.
What is the response of ocean circulation to changing boundaries, especially the Drake Passage, the Isthmus of Panama, and the Tethys Seaway? How does this vary in glacial and nonglacial eras?
The response of the atmosphere and oceans to orbital variations.
How have gravitational interactions with other planets, especially Jupiter, affected paleocirculation in the atmosphere and hydrosphere?
The history of the earth's magnetic field.
What is the nature of the magnetic field during a magnetic reversal? What is the detailed reversal and paleointensity history of the magnetic field in the past 200 million years?
The process and mechanism of evolution in marine organisms.
Have the details of evolution been characterized by continuous change or by punctuated equilibrium states in marine organisms?

thrust of OMDP, which essentially perished with the withdrawal of industry support (*Eos*, October 20, p. 705), was to drill deep holes with riser and well-control technology on or near the continental margins of the United States.

'Many of the data syntheses prepared for OMDP will be very useful to future scientific ocean drilling programs, whatever they may be called,' Larson said, 'but if the recommendations of COSOD are adopted, these programs will be worldwide in nature, will attack problems on the margins and in the deep sea, and will contain a strong element of participation from the international scientific community.'

Twelve scientific programs were identified as top priority drilling objectives by the COSOD working groups (see box).

Larson stressed four main points: (1) 'A worldwide program of long-term drilling is an essential component of research in the earth sciences.' The projects identified at COSOD would require at least a decade to complete. 'Many of these programs can be accomplished with the presently available drill ship *Glomar Challenger*, but the extended capabilities of the *Glomar Explorer* are required to accomplish a large number of other objectives. It was the unanimous consensus of the conference attendees and the Steering Committee that *Glomar Explorer* is clearly the preferable vessel for future scientific ocean drilling. It is recognized that the availability of *Glomar Explorer* is subject to a yet-to-be-conducted cost analysis and that the drilling system would almost certainly be operated without a riser and blowout prevention system for at least several years.' (2) 'Future ocean drilling must be part of a larger scientific program that includes adequate support for problem definition, site surveying, geophysical experimentation, and sample analysis.' (3) Integration of continental geology and marine geology should progress through scientific drilling programs. (4) International cooperation should continue and expand.—*BTR*

NASA Combines Two Offices

The National Aeronautics and Space Administration has completed plans for combining its Office of Space Science and its Office of Space and Terrestrial Applications. The new organization was effective December 3.

The new Office of Space Science and Applications will retain the programs and responsibilities of the two program offices with the exception of the Technology Utilization Program, which has been transferred to the Government/Industry Affairs Division of the Office of External Relations.

Andrew J. Stolan has been appointed acting associate administrator of the Office of Space Science and Applications; Samuel W. Keller has been appointed deputy associate administrator. Stolan was acting associate administrator for Space Science, and Keller was deputy associate administrator for Space and Terrestrial Applications.

EAR Reorganizes

The Division of Earth Sciences (EAR) at the National Science Foundation (NSF) recently reorganized, Division Director Robin Brett told NSF's National Science Board at its November meeting. EAR had been segregated into four programs: geology, geophysics, geochemistry, and petrology; the reorganization divides EAR into eight programs (see table).

New Organization of NSF's Division of Earth Sciences

Programs	Program Director
Stratigraphy and Paleontology	John Lance
Environmental Geosciences	Alan Gaines (Acting)
Crustal Structure and Tectonics	Tom Wright
Seismology and Deep Earth Structure	Leonard Johnson
Experimental and Theoretical Geophysics	Murli Manghnani
Petrogenesis and Mineral Resources	Elaine Padovani
Mantle Geochemistry	Elaine Padovani (Acting)
Experimental and Theoretical Geochemistry	Alan Gaines

The reorganization aims 'to minimize gaps between programs, to emphasize studies of the continental crust, to emphasize the new interdisciplinary nature of [earth sciences], and to bring into prominence the societal issues the field can address,' Brett explained.

Interdisciplinary approaches to earth science research are occurring with increasing frequency and are manifested in the proposals EAR receives, Brett said. Since 1965, the number of proposals has increased 330%. However, the budget has not tripled. EAR's budget has increased 40% (constant dollars); the average grant has diminished from about $48,000 to less than $25,000 (1972 dollars), Brett said. EAR's reorganization will aid in the efficient handling of the increased number and types of proposals.—*BTR*

Geophysicists

Seven AGU members were elected to offices of the American Association for the Advancement of Science. *Clark R. Chapman* was selected as the member-at-large of the Astronomy section committee. *James F. Davis* was elected member-at-large of the Geology and Geography section committee, and *Randolf W. Bromery* was elected a member of the electorate nominating committee of the section. In the Atmospheric and Hydrospheric Sciences section, *Hans A. Panofsky* is chairperson-elect, and *Barry Saltzman* was elected member-at-large of the section committee. *William R. Holland* and *Warren M. Washington* were elected members of the electorate nominating committee of the Atmospheric and Hydrospheric Sciences section.

James Andrews has been chosen technical director of the Naval Ocean Research and Development Activity (NORDA). He had been serving as the director of NORDA's Ocean Science and Technology Laboratory. He has served twice as chief scientist for the Deep Sea Drilling Project.

M. King Hubbert, an AGU Life Member, was awarded Columbia University's 1981 Vetlesen Prize at a dinner at the university on December 3. The Vetlesen Gold Medal carries with it a prize of $50,000. Previous winners of the prize include *J. Tuzo Wilson, Chaim Leib Pekeris, William A. Fowler, S. Keith Runcorn, Allan V. Cox, Richard Doell, Francis Birch, Sir Edward Bullard, Jan Hendrick Oort, Arthur Holmes, Pentti Eelis Eskola, Sir Harold Jeffreys, Felix A. Vening Meinesz,* and *Maurice Ewing.*

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POSITIONS AVAILABLE

Iowa State University of Science and Technology/Department of Earth Sciences.

Applications are invited for two tenure track faculty positions. The rank for each is at the assistant or associate professor level, dependent upon qualifications. The successful applicants will be expected to develop strong research and graduate student programs. Teaching duties will include undergraduate and graduate courses in the areas of expertise.

Mineral Resources Economic Geology. One position is in mineral resources/economic geology. An applied field orientation is preferred. Iowa State has established a Mining and Mineral Resources Research Institute and an interdepartmental minor in Mineral Resources in order to support and develop research and education in this area. In addition to the appointment in the Department of Earth Sciences there will be full opportunities to interact with these programs.

Geomorphology: The second position is in the general field of geomorphology. Additional expertise in an area related to geomorphology, such as groundwater, engineering geology or remote sensing is also desired. A person with an applied field orientation is being sought.

Each appointment will be on an academic year basis. Opportunities are available for summer teaching appointments. Salaries will be commensurate with qualifications. Application deadlines for both positions are February 15, 1982; later applications will be accepted if a position is not filled. Positions are both currently available and are expected to be filled no later than fall, 1982. For application information please write to:

Bert E. Nordlie
Department of Earth Sciences
253 Science I
Iowa State University
Ames, Iowa 50011

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Princeton University/Water Resources Program, Department of Civil Engineering. Department of Civil Engineering invites applications for a tenure track, three-year appointment at the assistant professor rank beginning on or before September 1982. Responsibilities include graduate and undergraduate teaching in hydrology and water resources, and participation in research into either hydrological processes associated with infiltration and unsaturated flow or chemical processes and transport in the unsaturated zone. Candidate must have Ph.D. degree with demonstrated teaching ability and scholarship.

Submit resume and references to:

Eric F. Wood, Director
Water Resources Program
Department of Civil Engineering
Princeton University
Princeton, NJ 08544.

Princeton University is an affirmative action/equal opportunity employer.

Research Associate/Electron Microprobe. The Electron Microscopy Center at Texas A&M University invites application for the position of Electron Microprobe Specialist. Applicants should possess a working knowledge of WDS and EDS spectrometers and accompanying computer and software programs and preferably have had experience in the Geological Sciences.

The primary duties of the position are to oversee and maintain (with the aid of service contracts) the electron microprobe and ancillary equipment and to assist in teaching graduate course laboratories dealing specifically with electron microprobe analysis. Salary will be up to $25,000/12 months.

Applicant should send supporting data and letters of recommendation to:

Dr. E. L. Thurston
Texas A&M University
Biological Sciences Building
College Station, Texas 77843

Texas A&M is an equal opportunity/affirmative action employer.

Postdoctoral Research Fellowship. The Department of Theoretical and Applied Mechanics, University of Auckland, New Zealand, invites applications for a postdoctoral fellowship in Geothermal Reservoir Modelling. The fellow will be expected to assist with the development of modelling techniques and their application to New Zealand reservoirs. Applicants must have successfully completed the requirements for a Ph.D. or its equivalent before being eligible to take up the fellowship which will be available for 12 months from an agreed starting date during 1982. A monthly allowance of NZ$1,1519 will be paid and also an approved return airfare. Further information and application forms may be obtained from Dr. M. J. O'Sullivan, Theoretical and Applied Mechanics Department, University of Auckland, Private Bag, Auckland, New Zealand.

Applications close 1 March 1982.

Positions in Oceanography/VIMS. The Virginia Institute of Marine Science (VIMS)/School of Marine Science invites applications for two state funded, oceanography research and teaching positions at the levels of Senior Marine Scientist. VIMS is a broad-based marine science establishment with a mission to provide sound and timely advice to executive agencies and the legislature and to conduct incisive research programs. The School of Marine Science offers M.A. and Ph.D. programs with a faculty of 66 and 139 graduate students.

HEAD, DEPARTMENT OF GEOLOGICAL OCEANOGRAPHY (#113)

Applicants are sought with research interests in estuarine sedimentary geochemistry, dynamics of cohesive sediment transport, or estuarine and coastal morphodynamics. For further information contact Dr. Robert Byrne (VIMS), 804/642-2111 (Ext. 173).

ESTUARINE AND COASTAL HYDRODYNAMICS (Position #204)

A physical oceanographer with a strong interest in interdisciplinary approaches to complex estuarine and continental shelf problems is desired. For further information contact Dr. Bruce Neilson (VIMS), 804/642-2111 (Ext. 244).

Candidates for both positions should have established research credentials and be dedicated to furthering the research and educational programs of the Institute. Demonstrated ability to generate extramural support is expected. Salary range is $24,872 to $34,107 and faculty rank is commensurate with qualifications.

Applicants should send a comprehensive curriculum vita, reprints, and at least three letters of recommendation by February 1, 1982, stating specific position of interest, to: Employment Manager, Personnel Office, College of Wm & Mary, Williamsburg, VA 23185.

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POSTDOCTORAL POSITION IN MARINE CHEMISTRY

Woods Hole Oceanographic Institution invites applications for the position of Postdoctoral Investigator. This position is being offered for basic research on the chemistry of the particle flux in the ocean and on the chemistry of sediment-seawater interactions, with particular emphasis on the transport of trace metals and radionuclides. Preference will be given to applicants with training in radiochemistry, trace-element analysis, surface chemistry, or geochemical modeling. Send resume and names of three references to:

Personnel Manager
Box 54P

WOODS HOLE OCEANOGRAPHIC INSTITUTION

Woods Hole, MA 02543
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Surficial Geology/Ground Water. Utah State University. Tenure track position starting spring quarter of 1982 or fall quarter of 1982. Ph.D. required. Rank and salary negotiable. Surficial geology with emphasis on geologic field studies and ground water with attention to both geologic and geohydrologic aspects. Emphasis on the arid West. Closing date November 30, 1981. USU is an affirmative action equal opportunity employer. Department of Geology (07), Utah State University, Logan, Utah 84322.

Marine Research Associate III/Atmospheric Chemist. Design and implement experiments on the sea/air exchange of trace elements as part of SEAREX Program. Experience in trace element analysis desirable. Ph.D. in analytical, marine, or atmospheric chemistry required. Submit resume and two references by January 1, 1982 to: Employee Relations Officer, File # 090020, University Of Rhode Island, 80 Lower College Road, Kingston, R.I. 02881.

An affirmative action/equal opportunity employer, M/F.

Research Scientist/Chemical Oceanography. Princeton University, Department of Geological and Geophysical Sciences has an opening for a Ph.D. chemical oceanographer beginning January, 1982. The successful applicant will be in charge of field and laboratory operations for gathering, analyzing, and interpreting Ra-228/Ra-226 data. Once data are available the applicant will be expected to participate in developing 3-D models of these data. Experience in both radon scintillation counting and alpha spectroscopy are necessary. Skill in writing and operating sophisticated programs on large computers and extensive experience in working at sea are highly desirable.

Curriculum vitae, publications, and the names of three references should be sent to Jorge L. Sarmiento, Director, Geophysical Fluid Dynamics Program, 110 Guyot Hall, Princeton University, Princeton, New Jersey 08544. Princeton University is an equal opportunity/affirmative action employer.

Planetary Scientist. SUNY Stony Brook. The Department of Earth & Space Sciences, anticipates that a tenure track faculty position may become available for a PhD Planetary Scientist. Planetary science within this department spans the range of planetary atmospheres, cosmochemistry, and planetary geophysics. The candidate should have a demonstrated record of accomplishment. The appointee is expected to pursue an active research effort and will be responsible for teaching courses at the undergraduate and graduate level. Send vitae and names of 3 references to: Dr. Roger Knacke, Dept. of Earth & Space Sciences, SUNY Stony Brook, Stony Brook, NY 11794. SUNY Stony Brook is an EO/AA employer. AK

Crustal Geophysics/Tectonophysics or Sedimentology. The Department of Geology at the University of Kansas is seeking applicants at the assistant professor level for a potential addition to a tenure track position that will begin in August, 1982 or January, 1983. The appointment will be made in either crustal geophysics, tectonophysics, structural geology, or in sedimentology. The area in which the appointment will be made will depend upon the qualifications of the applicant and departmental needs. Duties include teaching in our introductory, undergraduate major, and graduate courses; advising students; supervising graduate student theses and dissertations; conducting original research; and providing service through administrative and professional activities. Applicants must have a Ph.D. in hand or expect to complete it by the end of the first year of employment at the University. Minimum salary at the assistant professor level will be $22,000, if the position is authorized.

Crustal Geophysics, Tectonophysics or Structural Geology. We will consider applicants from all fields of geophysics and structural geology who are interested in applying their expertise to understanding the structure and evolution of the earth's crust and who will complement the five existing geophysics faculty of the Department and the Kansas Geological Survey. The successful applicant will be expected to cooperate with current faculty in offering courses in the undergraduate and graduate level in geophysics, tectonics, or structural geology.

Sedimentology. We will consider applicants in any branch of sedimentology, but those with interests in studying carbonate rocks, diagenesis and sedimentary geochemistry, or the relationships of sedimentation and tectonics are preferred. The applicant will be expected to cooperate with present faculty in offering courses at the undergraduate and graduate levels that cover all aspects of the study of sedimentary rocks.

Persons who have responded to earlier advertisements this year for sedimentology and structural geology need not re-apply, but will be automatically considered. In the event that candidates are about equally qualified, preference will be given to applicants whose areas of interests will complement those of the other faculty or who will participate in the department's summer field geology teaching program.

Priority will be given to applicants whose files are complete by February 1, 1982. Applicants should send a letter of application, a resume (including publication list), transcripts of all college level work, and names of three references to:

Ernest E. Angino
Department of Geology
University of Kansas
Lawrence, Kansas 66045
Phone: (913) 864-3771.

The letter of application should include a statement of current and planned research interests and of courses that the applicant feels qualified to teach.

An equal opportunity/affirmative action employer. Applications are sought from all qualified people regardless of race, religion, color, sex, disability, veteran status, national origin, age, or ancestry.

Faculty Positions. *Two Faculty Positions in Geology.* Tenure-track positions in geology, assistant professorships. Ph.D. preferred or equivalent experience. Fall 1982.

Petrologist-Mineralogist. Candidate must be able to teach introductory geology, mineralogy, petrology, geochemistry, and optical mineralogy-petrography.

Invertebrate Paleontologist-Soft-Rock Geologist. Candidate must be able to teach courses in invertebrate paleontology, micropaleontology, sedimentation, and historical geology. Additional expertise in recent marine environments highly desirable.

Applicants are expected to do research in their areas of expertise, and to lead students' field trips. Strong teaching and research commitments expected. Submit applications with resume and copies of transcripts, and have three letters of recommendations sent to the Chairperson, Department of Earth & Space Sciences, Indiana University-Purdue University at Fort Wayne, Fort Wayne, Indiana 46805.

Indiana University-Purdue University is an equal opportunity/affirmative action employer.

Structural Geologist/University of Wyoming. The University of Wyoming, Department of Geology and Geophysics seeks applicants for a tenure track appointment in structural geology expected to be available beginning fall semester 1982 or earlier. Duties will include teaching of undergraduate and graduate courses in structural geology, supervising MS and PhD theses, and research in structural geology. Appointment at assistant professor level is preferred, but applicants requesting appointment at higher rank will be considered. Salary open. Applicants must have PhD degree and be versed in quantitative theory as well as field applications of modern structural geology and regional tectonics.

Applicants should provide, by January 1, 1982, a resume, three letters of reference, and a letter of application including a statement of current research interests and courses which the applicant feels qualified to teach. Applications should be sent to:

Dr. Robert S. Houston/Head
Department of Geology and Geophysics
University of Wyoming
Laramie, Wyoming 82071-3006.

The University of Wyoming is an equal opportunity/affirmative action employer.

Graduate Research Assistantships. Environmental science at the Oregon Graduate Center. Atmospheric and aerosol physics research programs in theoretical modeling of anthropogenic effects on stratospheric ozone and global temperature and in development and utilization of real time instrumentation for sulfur and carbon aerosols. Degree program provides for intensive research experience and maximum student-faculty interaction. $7500 stipend with remission of fees and tuition available to qualified Ph.D. students. Write Dr. Douglas F. Barofsky, Oregon Graduate Center, 19600 N.W. Walker Road, Beaverton, Oregon 97006.

Seismologist/University of Utah. Search extended: the University of Utah is expanding its geophysics program in the Department of Geology and Geophysics by adding a tenure track faculty member in seismology at the assistant to associate professor level. Applicants with backgrounds and specialties in seismic reflection, seismic imaging, and theoretical seismology will be given preference. The individual will be expected to teach undergraduate and graduate courses, and to pursue an active research program with graduate students. The department has modern teaching and research programs in geology and geophysics, and has close associations with the numerical analysis and data processing groups in computer science, electrical engineering and mathematics. The geophysics component of the department has strong research and teaching programs in seismology, electrical and electromagnetic methods, thermal properties of the earth, and potential fields. Current research in seismology includes: seismological and earthquake research utilizing a new PDP 11/70 computer with plotter and terminals; monitoring of the Intermountain seismic belt by a 55 station telemetered network utilizing a new on-line PDP 11/34 computer; major experiments in seismic refraction profiling, investigations of seismic propagation from synthetic seismograms, application of inverse theory to seismology, seismic properties of volcanic systems and allied research in tectonophysics. The closing date for applications is December 31, 1981. A Ph.D. is required for this position. Applicants should submit a vita, transcripts, a letter describing his/her research and teaching goals, and names of five persons for reference to William P. Nash, Chairman, Department of Geology and Geophysics, University of Utah, Salt Lake City, Utah 84112.

University of Utah is an equal opportunity/affirmative action employer.

Oceanographic Modeler. Ocean Data Systems, Inc. is seeking an applications oriented scientist to develop/adapt wave, HN and oil spill models for application in the Middle East on large CYBER computers. Position is in Monterey. Experience in commercial applications of varied oceanographic modeled output would be advantageous. Salary commensurate with ability and experience. Liberal benefits. Send resume to Mr. C. R. Ward, Ocean Data Systems, Inc., 2400 Garden Road, Monterey CA 93940.

University of Montana, Department of Geology/Two Positions: Tectonics and Paleontology. Applications are invited for two tenure track positions: tectonics with focus on western North America, and paleontology-biostratigraphy-paleoecology. Both positions begin September 1, 1982. Applicants must have the Ph.D. degree or expect completion by summer 1982. Send letter of application, resume, an outline of teaching and research interests, and other pertinent material and have at least three letters of recommendation sent to Donald W. Hyndman, Search Committee Chairman; University of Montana; Missoula, Montana 59812. Deadline for applications is March 15, 1982.

The University of Montana is an affirmative action/equal opportunity employer.

Hydrology: Tenure Track Position at Assistant or Associate Professor Level. Candidate should be a specialist in some quantitative aspect of hydrology with demonstrated skills in formulating hydrologic models, and a background in transport phenomena. Academic or professional credentials at Ph.D. level required. Starting date negotiable but could be as early as August 1982. Resumes, etc., should be received by March 1, 1982. Interested persons should request job description from Dr. E. S. Simpson, Chairman, Search Committee, Department of Hydrology and Water Resources, University of Arizona, Tucson, Arizona 85721.

Equal opportunity affirmative action employer.

STUDENT OPPORTUNITIES

Exxon Teaching Fellowship at University of Michigan-Geological Sciences. Applications are invited for a three-year fellowship in the PhD program, supported by the Exxon Education Foundation. Annual stipends will be $12,000, $13,500, and $15,000 for the first, second and third years, respectively, with full waivers for tuition and fees. The successful applicant will be a person who, at the time of the award, intends to pursue a college teaching career, is extremely articulate and has a demonstrably high quantitative and verbal aptitude, and is a U.S. citizen permanent resident. Regular admission and financial support applications must be received before February 1, 1982 to be considered. An extensive background in geological and cognate sciences is desirable. Unsuccessful applicants for the Exxon Fellowship are still eligible for our regular financial support. For further details contact: R. Van der Voo, Chairman, Department of Geological Sciences, University of Michigan, Ann Arbor 48109.

Graduate Research Assistantships in Marine, Atmospheric, and Sedimentary Geochemistry. Available for students leading to M.S. and Ph.D. degrees with specialization in the geochemistries of oceanic, estuarine, and sedimentary trace elements and nutrients, atmospheric particulates and gases, and sedimentary radiogeochemistry. Stipends for incoming M.S. candidates are $5700 for 9 mos., with additional summer awards up to $2800, and for advanced Ph.D. students are up to $10,000 for 12 mos. Persons with strong undergraduate majors in the basic sciences are encouraged to apply. Contact Prof. P. N. Froelich, Dept. of Oceanography, Florida State University, Tallahassee, FL 32306, 904-644-6700.

Geophysical Fluid Dynamicist/Physical Oceanographer. Applications are solicited for a junior faculty position in ocean physics or dynamics to begin in the academic year 1982–83. Areas of interest to the Department include analytical, numerical and laboratory modeling of physical processes and phenomena in the sea.

Yale University is an equal opportunity/affirmative action employer and encourages women and members of minority groups to compete for this position.

Curriculum vitae, publications, and the names of three or more referees should be sent by 31 December 1981 to: Robert B. Gordon, Chairman, Department of Geology and Geophysics, P.O. Box 6666, New Haven, CT 06511.

Graduate Study in Oceanography/Oceanographic Engineering. Research Assistantships and research fellowships are available for graduate study in Physical and Chemical Oceanography, Oceanographic Engineering, and Marine Geology and Geophysics leading to a Ph.D. or Sc.D. degree conferred jointly by the Woods Hole Oceanographic Institution and the Massachusetts Institute of Technology. The awards cover tuition and provide an average monthly tax-free stipend of $540 to $590. Research topics available to students reflect the interests of the more than 100 doctoral scientists and engineers at WHOI and the faculties of ten different departments at MIT.

The program encourages applications from students with an undergraduate degree in any of the natural sciences or engineering. For additional information please contact: The MIT/WHOI Joint Program in Oceanography/Oceanographic Engineering at either: The Education Office, The Woods Hole Oceanographic Institution, Woods Hole, MA 02543 or Room 54-911, The Massachusetts Institute of Technology, Cambridge, MA 02139.

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AGU

Nominees for Section Presidents

Statements of Candidates

(Statements from all candidates for office of section president will have been published by next month. Geodesy, Geomagnetism and Paleomagnetism, Hydrology, and Solar Planetary Relationships appeared in the December 15 issue. The statements for Meteorology and Tectonophysics appear below. The remainder will follow over the next few weeks.)

W. Lawrence Gates (Meteorology)

I believe that one of the great values of the AGU to meteorologists is to provide contact with their colleagues in other geophysical sciences. By broadening their view to include aspects of hydrology, oceanography, glaciology, and aeronomy, for example, a meteorologist is better able to appreciate the behavior of the atmosphere. The interaction among several geophysical disciplines is especially important in problems such as weather modification and climate. This interaction should be encouraged in the training of new members of the profession. I think the AGU's spectrum of meetings, conferences, and publications are well suited to promoting such interdisciplinary interests, and I would give them my full support.

Fred D. White (Meteorology)

To be president of the AGU Section on Meteorology is an honor. If elected, I propose no major changes. To me, the quality of a professional society depends on the quality of its publications and scientific meetings. AGU rates high on both of these points. I do favor constantly trying to improve the interdisciplinary aspects of both the Spring and Fall AGU meetings. Meteorologists must try to communicate better with their fellow scientists in related fields. AGU meetings are a good place to commingle, both in the halls and in the meeting rooms.

Thomas J. Ahrens (Tectonophysics)

Tectonophysics in its broadest sense provides a synthesis of what we know of the solid earth, and its pursuit as a basic science is socially important. I believe it is becoming more and more appropriate for both the future of our society and our science for officers of organizations such as the AGU to speak out vigorously in favor of public, that is, government, support for basic research in geophysics. Private support of basic and applied research in our society also needs continuing tax incentives. A sound argument can be made for the importance of earth and planetary sciences, including geophysics, in the provision of a continuing and growing framework for the exploration for hydrocarbon, carbon, and nuclear fuels as well as metallic and nonmetallic raw materials, which both the developed and underdeveloped world will need in the foreseeable future. Geophysics has also demonstrated a role in such areas as the rationale for siting of facilities that are becoming increasingly important to our society, such as nuclear power plants, spent fuel repositories, and hydrocarbon pipelines and terminals. The intelligent management of both fresh and geothermal water reservoirs as well as liquid wastes depends on many aspects of our understanding of the physics of fluid flow in the earth's crust.

It is clear that the products of geophysical research have much to offer society in the reduction of hazards to life and property from earthquakes and volcanoes. I strongly support current efforts to keep a deep-sea drilling program viable. I believe scientific drilling, both on land and the seafloor, is needed to define the geophysical and geochemical environment of the earth, which bears heavily on the above issues and provides constraints on the processes taking place in the earth's mantle.

Finally, support of vigorous programs in space science and the chemistry and physics of the oceans and atmosphere needs to parallel support of solid-earth geophysics.

Johannes Weertman (Tectonophysics)

If elected, I will use the 2-year period during which I am president-elect for the purpose for which it is obviously intended: to become very well informed about the affairs of the Tectonophysics Section as well as those of the Union, to find out the strengths and weaknesses of the section, and to sound out the views and the advice of the members and of the present and past officers of the section. I will represent and promote to the best of my ability the interests of the Tectonophysics Section within the Union but will put the well-being of the Union ahead of that of any section. Our section has been very well run and led in the past, and I will try to emulate the example of our previous presidents. Since we are part of an American organization, I would like to see the national meetings of the Union switched much more regularly to the larger cities all over the country. If recruitment of new members is a problem to the Union—and it is—what better way to recruit than by bringing our national meetings into various sections of the country.

AGU Congressional Science Fellowship

The individual selected will spend a year on the staff of a congressional committee or a House or Senate member, advising on a wide range of scientific issues as they pertain to public policy questions.

Prospective applicants should have a broad background in science, be articulate, literate, flexible, and able to work well with people from diverse professional backgrounds. Prior experience in public policy is not necessary, although such experience and/or a demonstrable interest in applying science to the solution of public problems is desirable.

The fellowship carries with it a stipend of up to $25,000 plus travel allowances.

Interested candidates should submit a letter of intent, a curriculum vitae, and three letters of recommendation to AGU. For further details, write Member Programs Division, Congressional Fellowship Program, American Geophysical Union, 2000 Florida Avenue, N.W., Washington, D.C. 20009.

Deadline: March 31, 1982.